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CATEGORIZATION OF SHIPBOARD MACHINERY FOR APPLICABILITY TO GAS BEARINGS

by

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TECHNICAL REPORT

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FOR APPLICABILITY TO GAS BEARINGS

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INTRODUCTION

There are many pieces of marine machinery which might be adapted to gas bearings. More important, there are machine types which can benefit by improved reliability and maintainability, reduced size, reduced noise, lower overall cost, etc., by using process fluid-lubricated (PFL) bearings.

Process fluid lubrication is a broad term which includes hydrodynamic and hydrostatic bearings. The process fluid is any fluid required to pass through a machine and upon which the machine does work or vice-versa. Air, steam, oil, and water are those process-fluids normally encountered in Naval machinery.

The final report covering work done on Contract Nonr-4535(00) consists of four parts which correspond to the following tasks.

1. State-of-the-Art of Gas-Bearing Turbomachinery (MTI-65TR5-I)
2. Gas Bearing Design Charts (MTI-65TR5-II, Volumes 1 and 2)
3. Categorization of Shipboard Machinery for Applicability to Gas Bearings (MTI-65TR5-III)
4. Example Application of Gas Bearings to Shipboard Machinery (MTI-65TRIV)

The purpose of this part (III) of the final report is to arrive at a logical list of machinery that can be designed for PFL. The method used by MTI in making the selection is shown and explained so that the marine engineer can apply similar techniques to his own activities. In addition, a machine is selected for a design study for Task 4 (Part IV).

Machinery must be designed for process fluid lubricated bearings, rather than merely "adapted" to it, once it is determined that PFL should be used. This makes it doubly important to make early and firm decisions to use PFL in any design program. This part of the report will aid considerably in making that early decision.

RESULTS AND CONCLUSIONS

Using a matrix comparison approach, a list has been compiled of the naval machinery that gives high promise for substantial gains from the application of a PFL system. Following is the list in order of rank for potential gains and adaptability:

Ship's service generator - steam
Ship's service generator - gas
Auxiliary turbine - steam (small)
Auxiliary turbine - steam (medium size - light duty)
Forced draft blowers
Fans
Turbomachinery type air compressors
Auxiliary turbine - air (light or medium size, light duty)
Auxiliary turbine - steam (medium size - severe duty)
Auxiliary turbine - air (medium size, severe duty)
Motor-generator set (small)
Auxiliary motors and generator (small size, light duty)
Motor-generator sets (medium size, light duty)
Motor-generator sets (medium size, severe duty)
Auxiliary motors and generators (medium size, severe duty)

We recommend consideration of each category for more detailed and exact design studies for a rigorous quantitative evaluation of these gains.

In particular, we recommend an immediate design study of one of the above to establish beyond doubt the potential of PFL in general for adaptable marine machinery. The forced draft blower unit is our choice.

The matrix approach, explained in detail, in the following pages, proved to be a powerful tool for listing by rank the relative merits of the large number of factors which were considered. In our opinion this same basic method could very well be used in other evaluation studies where the Naval designer must sort out a complex set of variables but is limited by qualitative data.

For this study one matrix was used to determine the adaptability of a PFL bearing to various classes of machinery, and another was used to determine the

benefits to be gained by using PFL bearings. Use of the matrices allowed generation of a longer list of candidate machinery than originally anticipated and enabled the preferential listing noted above.

MATRIX 1

Matrix 1 lists Machinery Class versus Operating Conditions of the machinery class. The matrix is used in finding the adaptability of each class of machinery to PFL bearings by using a suitable-number rating system. The numbers used in this study were chosen so that a high number means that PFL bearings are easily designed for a mode of operation appropriate to a class of machinery. For each class of machinery a number is placed in the columns that describe the mode of each operating factor encountered by the machine. The operation conditions of importance to bearing selection include the nine items heading the various columns. These are:

Operating Factors	Possible Modes
duty	continuous (stops and starts at very long intervals)
	intermittent (many starts and stops per day)
speed	variable (operates over a wide speed range)
	constant
	high (over 4000 RPM)
	low
rotor	large (1000's of pounds)
	medium (100's of pounds)
	small (10's of pounds)
dynamic loads	light (acceleration loads less than 2g)
	medium
	high (acceleration loads over 10g)
shock (intermittent, high amplitude loads)	light (less than 10g)
	severe (more than 10g)
process fluid	gas
	vapor (condensible at bearing temps.)
	liquid

Operating Factors	Possible Modes
temperature	low (less than -65 F)
	ambient
	high (more than 200 F)
contamination	clean (no particles greater than about 1/4 of the minimum film clearance — varies with installation)
	normal
	dirty (particles greater than about 3/4 of the minimum film clearance — varies with installation)
vibration (continuous low amplitude oscillation)	low (less than 1 g)
	normal
	high (more than 4 or 5 g's)

The values used to define the "mode" of operation in the above listing are intended only to give an idea of the magnitudes involved.

Shock and dynamic loads as imposed on bearings have recently been illuminated as factors that can be accommodated by gas bearings. Ship motion can be designed for, according to results of Contract Nonr-4358(00)*, by finding the imposed dynamic load and designing the bearings to accommodate it as if it were a steady-state design. At worst, the bearing may be slightly larger than it would be for a stationary application. Actual design for these conditions can be done as soon as motion spectrums for various applications are known.

The shock tests executed on Contract Nonr-4358(00) show that there is a good possibility of sustaining high shock loads if momentary rubbing can be tolerated. Actually, those tests were carried out with both hydrostatic and hydrodynamic journal and thrust bearings until the shaft failed from shock. The bearings were still intact and operable after that severe treatment. In any case, proper selection of bearing surface materials will allow rubbing and, therefore,

operation under shock and vibration conditions. The rapid progress of this work will soon permit practical PFL bearings for heavy shock service.

Table I shows the matrix used to determine adaptability to PFL bearings. Rating numbers are shown inserted. The summation of the numbers used in the matrix for a class of machinery will be higher for machinery more adaptable to PFL bearings. The number (10) in a column indicates operating requirements are easily met with process-fluid-lubricated bearings and the number (1) indicates extreme difficulty. The number (0) indicates that adaptability presently is impossible. The summations are shown for each class of machinery. However, when a (0) is used anywhere in the matrix for a class of machinery, the entire summation is set equal to zero. Within a single class of machinery there may be a range of adaptability numbers because of several types of installations. The summation then appears as a range.

The summations of the adaptability numbers used in Table I result in the following adaptability rating (the higher the number, the more adaptable is the machinery to process fluid lubricated bearings):

Main Propulsion Turbines - steam	66-71
Main Propulsion Turbines - gas	63-68
Main Propulsion Engines - Diesel	0
Ship's Service Units - steam	71
Ship's Service Units - gas	70-75
Ship's Service Units - Diesel	0
Pumps - water	68-92
Pumps - fuel oil	89
Pumps - lube oil	83-88
Pumps - hydraulic systems	69-70
Air compressors	0-82
Fans and blowers	69-89
Reduction gears	0
Shafting	69
Motors and generators	55-92
Auxiliary turbines - steam	63-82
Refrigerator compressors	0-82
Pumps - liquid metal	76
Auxiliary turbines - air	89-70
Centrifuge drive	87

TABLE I

NAVAL MACHINERY CATEGORIES FOR GAS BEARING APPLICATIONS
OPERATING REQUIREMENTS

Machinery Class	Duty		Speed				Rotor			Dynamic Loads			Shock		Process Fluid			Temp.			Contam.			Vibrat.		
	Cont.	Int.	Var.	Const.	High	Low	L	M	S	Lt	M	H	Lt.	Sev.	Gas	Vap.	Liq.	Low	Amb.	High	Cl.	Nor.	Dirt	Low	Nor.	High
Main Prop. Tbs.-Steam	10		5		10	10	5				5			1		5				5	10			10		
Main Prop. Tbs.-Gas	10	5	5		10		5	5			5			1	10					5		7		10		
Main Prop. Engs.-Diesel	10		5			10		5				0		1	10				10			7				1
Ship's Service Units-Steam	10			10	10			5			5			1		5				5	10			10		
Ship's Service Units-Gas	10	5		10	10			5			7			1	10					5		7		10		
Ship's Service Units-Diesel	10			10		10		5				0		1	10				10			7				1
Pumps -water	10	5		10		10		5	10	10			5				10		10	5	10	7	1		7	
Pumps -Fuel oil	10			10		10			10	10			5				10		10			7			7	
Pumps -Lube oil	10			10		10		5	10	10				1			10		10		10				7	
Pumps Hydraulic Systems	10	5	5	10		10			10			1		1			10		10		10				7	
Air Compressors		5		10		10		5		10		1	5		10				10			7		10		1

TABLE I (Cont.)

NAVAL MACHINERY CATEGORIES FOR GAS BEARING APPLICATIONS
OPERATING REQUIREMENTS

Machinery Class	Duty			Speed			Rotor			Dynamic Loads			Shock		Process Fluid			Temp.			Contam.			Vibrat.		
	Cont.	Int.	Var.	Const	High	Low	L	M	S	Lt	M	H	Lt.	Sev.	Gas	Vap	Liq.	Low	Amb.	High	Cl.	Nor.	Dirt	Low	Nor.	High
Fans & Blowers	10		5	10	10	10		5	10	10	5		5		10				10	5		7			7	
Reduction Gears	10		5		10		5	5	10			0		1		1			10		10			10		
Shafting	10		5			10	5			10				1		10			10			7				1
Motors & Generators	10	5	5	10	10	10		5	10	10	5		5	1	10	5	10	5	10	5	10	7			7	
Auxiliary Turbines-steam	10	5	5	10	10			5	10	10			5	1		5				5	10				7	
Refrig. Compressors		5		10	10	10		5	10	10		0	5			5		5			10			10		1
Pumps Liquid Metal	10		5			10		5		10				1			10			5	10			10		
Auxiliary Turbines-Air	10	5	5	10	10			5	10	10			5	1	10				10			7			7	
Centrifuge Drive		5		10	10				10	10			5				10		10			7		10		

LEGEND:

Cl - Very clean fluid
Amb - Ambient temp. (30-200 F)
Liq - Liquid
Vap - Vapor (steam, etc.)
Gas - Gaseous medium
Sev - Severe
Dirt - Dirty
Nor - Normal

Cont - Continuous
Int - Intermittent
Var - Variable
Const- Constant
L - Large
M - Medium
S - Small
Lt - Light
H - High

It is important to note that there are cases which are not covered by the numbering system used in Table I. Several of these follow:

Even if the adaptability rating is poor, PFL bearings may be better suited than other bearing types. This is especially true in applications such as liquid metal pumps where contamination by other lubricants cannot be tolerated. Thus, the above numbering system serves only as a first indication of adaptability of machines to PFL bearings.

Design approaches different from those presently used may open up for some machinery classes if PFL bearings are used. An example of this is high-speed rotary air compressors — as opposed to reciprocating air compressors.

Economic advantages of PFL bearings for specific applications may eventually outweigh poor adaptability for some of the machinery classes. Such potential advantages may accrue because of simpler installation and less overall maintenance than other bearing types. Under these circumstances, the more difficult applications for PFL bearings may be worthwhile.

The total system must be considered in determining the adaptability of machinery to PFL bearings. For instance, even if a particular part of the system is adaptable to PFL bearings, there may be another part of the system that can neither be adapted to them nor divorced from the rest of the system. Table II indicates the system adaptability of machinery categories and systems.

Considering that a system with adaptability numbers above 70 can, with development, be adapted to PFL bearings, the machinery classes that can be rated "adaptable are:

Centrifuge drives
Water pumps
Motor driven fuel oil pumps
Motor driven lube oil pumps
Fans and blowers
Refrigerators with turbomachinery components
liquid metal pumps
Motor generator sets
Turbomachinery type air compressors

TABLE II

ADAPTABILITY OF NAVAL MACHINERY SYSTEMS TO PROCESS FLUID LUBRICATED BEARINGS

High Numbers Indicate Easy Adaptability

Machinery Class	Previously Indicated Adaptability From Table I	Other Possible System Components, Part of Single Assembly	Least Adaptable Component of System	Overall System Adapt-ability
Main Propulsion Turbine - Steam	71	a) Reduction gears Shafting	a) Reduction gears	0
		b) Alternator	b) Turbine	71
Main Propulsion Turbine - Gas	68 (continuous duty) 63 (Intermittent duty)	a) Reduction gears Shafting	a) Reduction gears	0
		b) Alternator	b) Turbine	68
Main Propulsion Engine - Diesel	0	a) Shafting Alternator	a) Diesel engine	0
Ship's Service Units - Steam	71	a) Alternator Gear Reduction	a) Gear Reduction	0
Ship's Service Units - Gas Turbine	75 (Continuous duty) 70 (Intermittent duty)	a) Alternator Gear Reduction	a) Gear Reduction	0
Ship's Service Units - Diesel	0	a) Alternator	a) Diesel	0
Pumps - Water	92 (Continuous duty, small, amb. temp. clean)	a) Turbine Gear Reduction	a) Gear Reduction	0
	* -5 for intermittent duty -5 for medium size -5 for high temperature -3 to 9 for dirtiness	b) Motor	b) Pump	92-68
Pumps - fuel oil	89	a) Turbine Gear Reduction	a) Gear Reduction	0
		b) Motor	b) Motor/pump	89
Pumps - lube oil	88 (small size)	a) Turbine	a) Gear Reduction	0
	83 (medium size)	b) Motor	b) Pump	88-83

* Subtract these numbers from basic rating if the indicated operating condition applies to the particular case.

TABLE II (Cont.)

Machinery Class	Previously Indicated Adaptability From Table I	Other Possible System Components, Part of Single Assembly	Least Adaptable Component of System	Overall System Adapt-ability
Pumps - Hydraulic Systems (non-positive displacement)	79 (continuous duty, constant speed) * -5 for variable speed -5 for intermittent duty	a) Motor	a) Pump	69-70
Air Compressors	0 (reciprocating type) 73 (turbomachine type)	a) Motor a) Motor b) Turbine	a) Compressor recip.) a) Compressor b) Turbine	0 73 67
Fans & Blowers	89 (constant speed, small light dynamic loads, ambient temperature (fan)) * -5 for high temp. -5 for medium dynamic loads -5 for medium size -5 for variable speed	a) Motor b) Turbine Reduction Gear c) Turbine	a) Motor/fan b) Reduction gear c) Turbine	89-69 68 72-89
Reduction Gear	0			
Shafting	69			
Motors & Generators	92 (continuous duty, constant speed small, light shock, gas or liquid lubed, ambient temp. clean) * -3 for normal duty -5 for high or low temp. -5 for vapor lube -4 for severe shock -5 for medium size -5 for variable speed -5 for intermittent duty -5 for medium dynamic loads			

TABLE II (Cont.)

Machinery Class	Previously Indicated Adaptability From Table I	Other Possible System Components, Part of Single Assembly	Least Adaptable Component of System	Overall System Adapt-ability
Auxiliary Turbine - Steam	82 (continuous duty, constant speed small size, light shock) * -4 for severe shock -5 for medium size -5 for variable speed -5 for intermittent duty			
Auxiliary Turbine - Air	89 (Continuous duty, constant speed, small size, light shock) * -4 for severe shock -5 for medium size -5 for variable speed -5 for intermittent duty			
Refrigerator compressors	80 (small size, turbo machine	a) Motor	a) Compressor	80-75
	0 (reciprocator)	b) Motor	b) Compressor	0
Pumps - Liquid Metal	76	a) Motor b) Turbine	a) Pump b) Pump	76 76
Motor/Generator sets	(same as Motor and Generators)			
Centrifuge drives	87	a) Turbine b) Motor	a) Turbine b) Centrifuge	84 87

It is apparent that the elimination of reduction gearing would considerably widen the list of candidate systems for process-fluid bearings. This would allow inclusion of these additional machine types:

Turbo pumps - lube oil
Turbo pumps - fuel oil
Turbo pumps - water
Ship's service units - steam
Ship's service units - gas
Main Propulsion Turbines - steam
 - gas (marginal)

MATRIX 2

The second matrix is used to determine if an overall benefit can accrue by designing particular classes of machinery for PFL bearings. The matrix consists of a list of classes of machinery arrayed against a list of evaluation factors. The evaluation factors are design parameters that must be met by a specific machine. The matrix is filled-in to indicate whether or not the use of PFL bearings will allow a machine to be improved with respect to each evaluation factor.

The matrix serves as a check list to the marine engineer to assure that all major factors are considered when evaluating the overall desirability of adapting a machine to PFL bearings.

An explanation of the evaluation factors follows:

Evaluation Factors

1. Weight

   Weight of complete unit including supporting auxiliaries and services.

2. Space

   Total space occupied by unit, in cubic feet, including supporting auxiliaries and services. In some cases, proportions as well as volume may be important.

3. Life and Reliability

   Total life is important from a replacement cost standpoint, and it

should be equal to the useful life of the vessel. Reliability must be predicted for the mission or missions for which the vessel is intended, and is related to life.

4. Cost

   The total cost of the equipment as installed in the vessel with auxiliaries and supporting services.

5. Maintenance

   The cost of overhaul and repair of the equipment to retain the required reliability over its design life.

6. Accessibility for Maintenance

   Ease of performing maintenance in the installed location. This can affect the total cost of performing necessary maintenance and directly affects practicality of ships force maintenance.

7. Shock Resistance

   Ability to withstand shock loadings externally applied, according to MIL specifications.

8. Ambient Conditions

   The effect of ambient conditions of temperature, pressure, water and dirt on the operation, life and reliability of the equipment in service.

9. Noise Level

   The contribution the equipment makes to the noise level of the machinery space in the active bands as specified in the appropriate MIL specifications.

10. Contamination

    The possibility and degree to which the bearing lubricant can contaminate the working fluid, and the degree of contamination that can be tolerated in the working fluid.

11. External Leakage

    The possibility and degree to which the working fluid can leak into the machinery space or contaminate the lubricant and the amount of

such leakage or contamination that can be tolerated. Also, the difficulty and importance of preventing leakage of lubricant into the machinery space.

12. Bearing Losses

    The losses attributable to the bearing system, including friction losses, leakage losses of working fluid and power required by lubricant supply system and/or other auxiliaries.

13. Cooling Requirements

    The extent to which external cooling is required to remove the bearing system losses and/or maintain the bearing regions at their maximum allowable operating temperatures.

14. Operating Adjustment & Supervision

    The frequency with which adjustments must be made to the bearing system during starting and operation and the degree to which the system must be monitored and supervised during operation.

Several of the evaluation factors deserve some discussion before proceeding with the categorization exercise:

Weight and Space

Generally, turbomachinery is smaller and lighter than positive displacement machinery handling the same process fluid. This is basic to fluid machinery design and need not be discussed further here. Also, generally basic to machine design is that higher rotative speeds mean smaller machinery. The use of PFL bearings, especially with gas, will usually allow high rotative speeds because low losses and long life are possible with them.

Contamination and External Leakage

PFL bearings negate the need for introducing a foreign substance into the vicinity of the process fluid. Also, the process fluid can be sealed completely within a machine using the process fluid as the lubricant. This assures that the fluid will not contaminate the environment and that the process fluid will not, itself, be contaminated.

Life, Reliability and Maintenance

High reliability and low maintenance are natural advantages of gas bearings over other bearing types. A well-designed and well-applied, gas-lubricated bearing will operate with no wear. This normally assures long life and low maintenance costs.

Starting and stopping poses a limitation to the above statement so far as hydrodynamic bearings are concerned. Here, surface materials are of importance since there will be limited rubbing during starting and stopping.

The effectiveness of the materials depends upon the gas, the temperature, loading, etc. In any case, the basic life limitation on gas-lubricated hydrodynamic bearings is the accumulated rubbing associated with lift-off at the start and with stopping. However, materials are available which limit wear to very low rates.

Another possible limitation in bearing life is fretting corrosion at the pivots of hydrodynamic, tilting-pad bearings. Material selection and proper design for Hertzian stresses normally reduce the severity of wear to an insignificant amount.

Material selection, design, and wear of pivots is presently under investigation. The above limitations are of a lesser order of magnitude than those resulting from the use of rolling contact bearings. This makes it clear that, in a well-controlled environment, gas-lubricated bearings will have exceptionally long life and high reliability. The only maintenance required will be inspection of the system for dirt, corrosion, and surface wear. This assumes that proper bearing adjustments have been made in the original assembly and at each inspection.

Vibration and Shock

Momentary shock and rolling motion loads imposed by sea and battle action can be withstood by gas bearings as discussed under Matrix 1. PFL bearings suitable for Naval shipboard machinery can be designed that will not be subject to failure because of high-speed momentary rubs. Materials selection is the key to design for this factor as mentioned above under Life, Reliability, and Maintenance.

Cost

Gas-lubricated bearing systems need only a clean, controlled gas supply with which to operate. There is normally no need for a separate fluid pump or cooling system as required with any non-process-fluid-lubricated bearing. As a consequence, the auxiliary equipment cost for gas-lubricated bearings is small.

The equipment cost for controlling environment will vary with the application. Operation of gas bearings in a cool closed loop requires virtually no gas conditioning equipment. With open cycle, high temperature, corrosive gas operation, the conditioning equipment required would include filters, scrubbers, possibly heat exchangers, and a means of monitoring corrosion in the bearings. The conditioning equipment required will also depend on the type of bearing - hydrostatic or hydrodynamic. Hydrostatic bearings will usually require more gas cleaning than will hydrodynamic bearings since the lubricating gas is recirculated and can pick up dirt and contamination anywhere in the loop, and can progressively worsen unless cleaned.

Table III is the second matrix with the benefit value numbers inserted. The numbers used are positive if the benefit to be gained with the use of PFL bearings is positive. Summation of "benefit value" numbers for each machine will then indicate the overall benefit to the user of making the design change.

"Ability" to adapt was indicated in Table I. Ordinarily there should be both the ability and a clear benefit accruing to make the adaptation advisable.

The numbers used in Table III are applicable to a unit to be installed in a nuclear submarine. This gives more weight to Space, Operating, and Maintenance factors than for any other installations. For other applications it must be kept in mind that the number to be used depends upon the machine class and upon the installation since these will affect the relative importance of each evaluation factors.

The following numbers are used in Table III.

TABLE III
DEGREE OF GAIN IN EXCELLENCE OVER PRESENT SYSTEMS
BY USING PROCESS FLUID BEARINGS

Machinery Class	Adaptability number Table I	Weight	Space	Contamination	Ext. Leakage	Access	Bearing Loss	Ambient	Cost	Life & Rel.	Vibration & Shock	Cooling Req.	Operation	Maintenance	Noise Level	Summation excluding Vibration & Shock
Main Propulsion Turbines - steam	71	0	0	+5	0	0	+1	0	0	+1	-5	+5	+1	+5	0	+18
Main Propulsion Turbines - gas	68-63	0	0	0	0	0	+1	0	0	+1	-5	+5	+1	+5	0	+13
Main Propulsion Turbines - gas - Nuclear closed cycle	71-66	0	0	0	0	0	+1	0	0	+1	-5	0	0	0	0	+
Main Propulsion Engines - Diesel	0			Not Applicable												
*Ships Service Generator-steam	71	+5	+5	+5	0	+1	+1	0	0	+5	-5	+5	+1	+1	+1	+30
*Ships Service Generator-gas turbines	75-70	+5	+5	0	0	+1	+1	0	0	+5	-5	+5	+1	+1	+1	+25
Ships Service Generator - Diesel	0			Not Applicable												
Pumps-Water-Circulating	78	0	0	+1	0	0	0	0	+1	+1	-1	0	+1	+1	+1	+6
Pumps-Water-Condensate	87	0	0	+5	0	0	0	0	+1	+5	-1	0	+1	+1	+1	+14
Pumps-Water-Sanitary	73	0	0	0	0	0	0	0	+1	+1	-1	0	+1	+1	+1	+5
Pumps-Water-Fire & Bilge	73	0	0	0	0	0	0	-1	+1	-1	-5	0	+1	+1	+1	+2
Pumps-Water-Boiler Feed & Circulating	87	0	0	+5	0	0	0	0	+1	+5	-5	+1	+1	+1	+1	+16

TABLE III(Cont.)

Machinery Class	Weight	Space	Contamination	Ext. Leakage	Access	Bearing Loss	Ambient	Cost	Life & Rel.	Vibration & Shock	Cooling Req.	Operation	Maintenance	Noise Level	Summation excluding Vibration & Shock
Pumps-oil (non-rubbing surfaces)-lube 88-83	Already Being Used With Process Fluid Lubrication														
Pumps-oil (non-rubbing surfaces)-fuel oil 89															
Pumps-oil (non-rubbing surfaces)-hydraulic 79-69															
Pumps-liq. metal-reactor coolant 76															
Centrifuge drive (oil system) 87															
*Blowers-forced draft 74	+1	+1	+5	+1	+1	+1	0	+1	+5	-5	+1	+1	+1	+2	+21
*Fans-space ventilation 89-84	+1	+1	0	0	0	+1	+5	+1	+1	-1	+1	+1	+1	+1	+13
Compressors-air (reciprocating)-low pressure 0	0	0	+1	0	0	0	0	0	-5	-5	+1	+1	+1	0	-1
Compressors-air (reciprocating)-high pressure 0	0	0	+1	0	0	0	0	0	-5	-5	+1	+1	+1	0	-1
*Compressor-air (non-rubbing surfaces) 73	+1	+1	+1	0	+1	+1	0	+1	+5	-1	+1	+1	+1	+1	+15
*Compressors-freon (non-rubbing surfaces) 80	0	0	+1	0	0	0	0	0	0	-1	0	0	+1	+1	+3
*Auxiliary turbines-steam (small, light duty) 77	0	0	+5	+1	+1	+1	0	+1	+5	-1	+1	+1	+1	+1	+18
*Auxiliary turbines-steam (medium, light duty) 72	0	0	+5	+1	+1	+1	0	+1	+5	-1	+1	+1	+1	+2	+19
*Auxiliary turbines-steam (medium, heavy shock & vibration) 68	0	0	+5	+1	+1	+1	0	+1	+5	-5	+1	+1	+1	+2	+19

TABLE III(Cont.)

Machinery Class	Weight	Space	Contamination	Ext. Leakage	Access	Bearing Loss	Ambient	Cost	Life & Rel.	Vibration & Shock	Cooling Req.	Operation	Maintenance	Noise Level	Summation Excluding Vibration & Shock
Motors & Generators-DC Main Propulsion 70	0	0	0	0	0	+1	0	+1	0	-5	+5	+1	+1	0	+9
Motors & Generators-AC Main Propulsion 70	0	0	0	0	0	+1	0	+1	0	-5	+5	+1	+1	0	+9
*Motors & Generators-AC/DC Auxiliary service (small, light duty) 89	0	0	0	0	0	+1	0	+1	+1	-1	+1	+1	+1	+1	+7
*Motors & Generators-AC/DC Auxiliary Service (medium, light duty) 84	0	0	0	0	0	+1	0	+1	+1	-1	+1	+1	+1	+2	+8
*Motors & Generators-AC/DC Auxiliary Service (medium, severe duty) 80	0	0	0	0	0	+1	0	+1	+1	-5	+1	+1	+1	+2	+8
Reduction Gears Auxiliary units 0	0	0	0	+1	0	+1	0	+1	-10	-1	+1	+1	+1	0	-4
Reduction Gears Main propulsion 0	0	0	0	+1	0	+1	0	+1	-10	-5	+5	+1	+1	0	0
Shafting-Propeller 69	0	0	0	0	0	+1	0	+1	+1	-5	+5	+1	+1	0	+10
*Motor-generator sets Auxiliary same as motors & generators above	0	0	0	0	+1	+1	0	+1	+1	-1	+1	+1	+1	+2	+9
*Auxiliary turbine-air (small, light duty) 84	0	0	0	+1	+1	+1	+1	+1	+5	-1	+1	+1	+1	+1	+14

TABLE III(Cont.)

Machinery Class	Weight	Space	Contamination	Ext. Leakage	Access	Bearing Loss	Ambient	Cost	Life & Rel.	Vibration & Shock	Cooling Req.	Operation	Maintenance	Noise Level	Summation Excluding Vibration & Shock
*Auxiliary turbines-air (medium, light duty) 79	0	0	0	+1	+1	+1	+1	+1	+5	-1	+1	+1	+1	+2	+15
*Auxiliary turbines-air (medium, heavy duty) 75	0	0	0	+1	+1	+1	+1	+1	+5	-5	+1	+1	+1	+2	+15
Meaning of + number as the result of using PFL bearings	Weight will be reduced	Volume will be reduced	Less contamination between lubricant and process fluid	Less external leakage	Greater accessibility for repair or removal	Less losses	Less affected by ambient conditions	Less installed and operating cost	Greater life or reliability	Less susceptible to shock & vibration	Less lubricant cooling requirement	Less problem in operating	Less time/cost of maintaining operations	Less noise generation	

<u>Number/Value of Benefit</u>

± 1 very weak

± 5 medium

± 10 very important

Where (+) shows an improvement of the factor if PFL bearings were used, (-) shows an adverse effect by using PFL bearings, and (0) shows no effect.

The benefit values are defined as follows:

Very weak:	May have a slight influence in overall acceptability of the machine.
Medium:	Should be considered in machine choice for future systems.
Very Important:	Retrofit of present machine with a machine designed for gas bearing would be desirable.

The rating numbers are summed up for each machinery class in Table III. The results of Table III then indicate very grossly whether or not consideration should be given to use of PFL bearings in new designs. The marine engineer can, when the information is available to him, include other factors in Table III such as cost and complication of other developments (for instance, static converters to go along with high speed alternators). This aspect of the evaluation was beyond the scope of this report, however.

Those machinery classes with the highest positive summation are those showing the most potential benefit by using PFL bearings. Consider summed-up evaluation numbers of 5 and above as indicating a worthwhile gain. Then the following list of candidate machinery results:

Main propulsion turbines - steam
Main propulsion turbines - gas
Ship's service generator - steam
Ship's service generator - gas
Condensate pumps
Boiler feed and circulating pumps
Forced draft blowers
Fans
Refrigeration compressors (turbomachinery type)
Air Compressors (turbomachinery type)

Auxiliary turbine - steam (small or medium size, light or severe duty)
Auxiliary motors and generator (light duty, small or medium)
Shafting propeller
Motor generator sets, auxiliary
Auxiliary turbine - air (small or medium size, light or severe duty)
Water circulating pumps
Main propulsion pumps
Main propulsion motors and generators
Auxiliary motors and generators (severe duty, medium size)

This list narrows somewhat when only gaseous-process-fluids, i.e., gas bearings, are considered, becoming:

Main propulsion turbines - steam
Main propulsion turbines - gas
Ship's service generator - steam
Ship's service generator - gas
Forced draft blowers
Fans
Air Compressors (turbomachinery type)
Auxiliary turbine - steam (small or medium size)
Auxiliary motors and generator (small or medium size)
Motor-generator sets, auxiliary
Auxiliary turbine - air (small or medium size)
Main propulsion motors and generators

When the results of Tables I and III are combined so that "adaptability" and "Benefit gain" are both factored in, a listing results which shows the candidate machinery in order of desirability to design for gas bearings.

The following are the results:

Ship's service generator - steam
Ship's service generator - gas
Auxiliary turbine - steam (small)
Auxiliary turbine - steam (medium size - light duty)
Forced draft blowers
Fans
Turbomachinery type air compressors
Auxiliary turbine - air (light or medium size, light duty)
Auxiliary turbine - steam (medium size - severe duty)
Auxiliary turbine - air (medium size, severe duty)
Motor-generator set (small)
Auxiliary motors and generator (small size, light duty)
Motor-generator sets (medium size, light duty)
Motor-generator sets (medium size, severe duty)
Auxiliary motors and generators (medium size, severe duty)

This comprises the machinery types presently deemed advisable, from an overall point of view, to adapt to gas bearings.

Selection of First Machine for Design Study

Each candidate machinery class should eventually be considered for use with gas bearings. Design studies will show the true gains to be made. However, very few of these machines have been so studied. It is, therefore, important to consider the requirements for selecting the first such design study. There must, of course, be a need. Second, for economy, the cost of making such an adaptation should be modest; so a small, relatively simple unit should be selected. Third, the design must be easily evaluated in terms of shipboard service.

The forced draft blower has been shown to be adaptable to gas bearings; there are benefits to be gained by doing so; there is a need as reported by Naval personnel on shipboard problems; the unit is relatively small and simple; and the benefits would be easily assessible when installed. The cost of making a preliminary design is nominal. The cost of designing, building, and testing would be much less than for a more complicated machine. Gas bearings of a well-known type are directly applicable to the unit so that design could proceed immediately. All-in-all, the forced draft blower is a completely logical selection for a first machine to be subjected to a design study for use with gas bearings.

As a consequence of these criteria, the forced draft blower is selected as the example problem required in Task 4 of this contract. A preliminary design is reached in Task 4 that shows the benefits to be accrued by using steam lubricated hydrostatic bearings. The results of Task 4 are reported in MTI-65TR5-IV.

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13. ABSTRACT

A list is presented covering those shipboard machines which are logical candidates for gas bearing applications. The method used in making the selection is shown and explained. This consists of using one matrix to determine the adaptability of a process fluid lubricated bearing to various classes of machinery, and another to determine the benefits to be gained by using these bearings. These evaluations are then weighed to determine suitable candidate machines. In addition, a machine is selected for a design study in Part IV.

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